Nernst effect

590B

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September 30, 2009

- **Nernst effect**

Walther Hermann Nernst
1864-1941

Nernst-Ettingshausen effect (1^{st} NE)

$$E_y = N \frac{1}{B} \frac{dT}{dx}$$

Nernst-Ettingshausen effect (2^{nd} NE)

$$\frac{dT}{dy} = P I_x B_Z$$

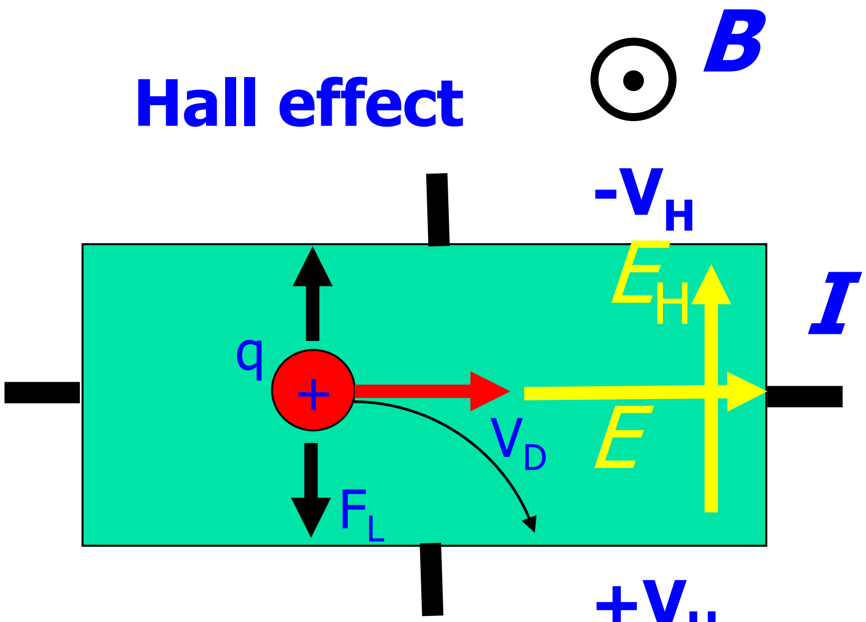
Albert von Ettingshausen
1850 - 1932

Graz 1887
Ludwig Boltzman and coworkers

Thesis 1887: Electromotive forces produced by magnetism in heated metal plates

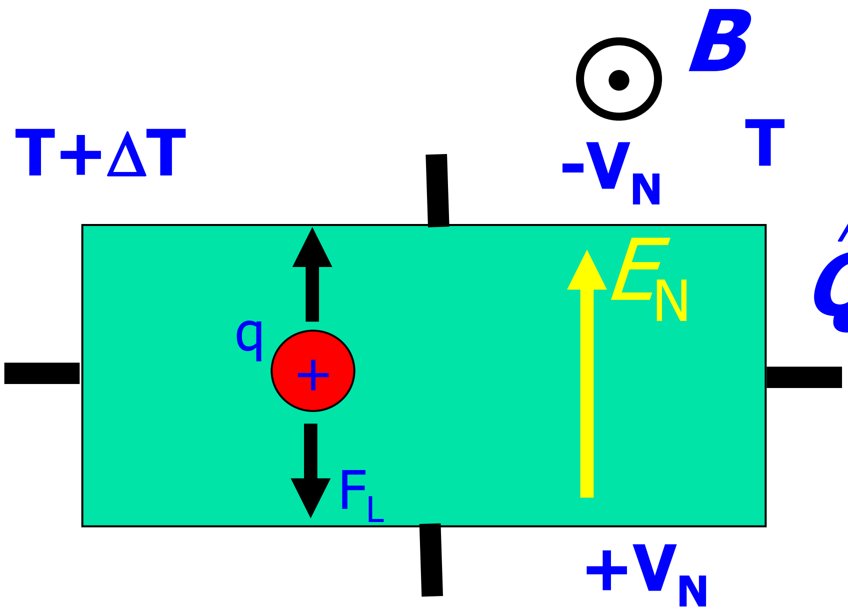
Third law of thermodynamics (Nobel prize 1920)
Nernst glower
Bernstein-Siemens-Nernst electric piano

$$V_H = R_H \frac{IB}{d}$$



Transverse voltage
Longitudinal current
Magnetic field

Nernst effect
or 1st Nernst-Ettingshausen effect

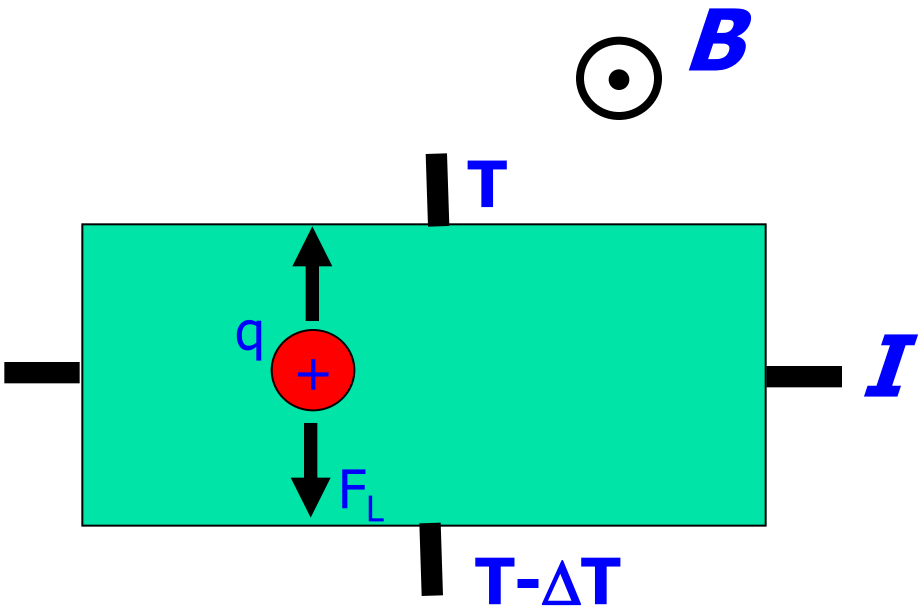


$\hat{Q} = \kappa \Delta T$

$$N = \frac{E_y B_Z}{dT / dx}$$

Transverse voltage
Longitudinal heat current
Magnetic field

Ettingshausen effect
or 2nd Nernst-Ettingshausen effect



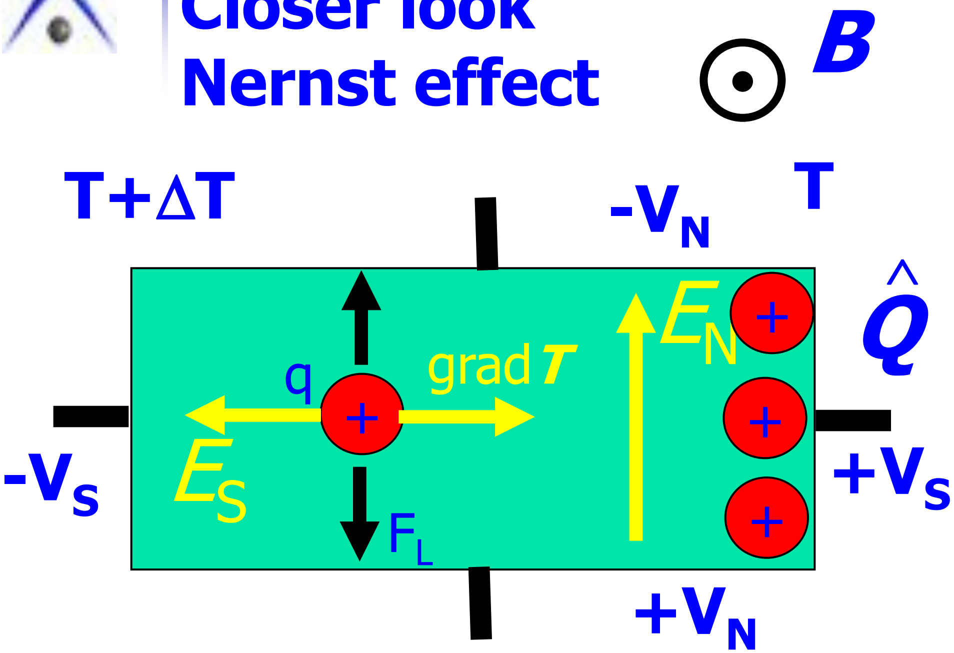
$$\Delta T = P\frac{BI}{d} - \frac{1}{2}\frac{\rho I^2}{d^2\kappa}$$

d-sample thickness
κ- thermal conductivity
ρ- electrical resistivity

Transverse thermal gradient
Longitudinal electrical current
Magnetic field

Can be used for thermoelectric cooling

Closer look
Nernst effect

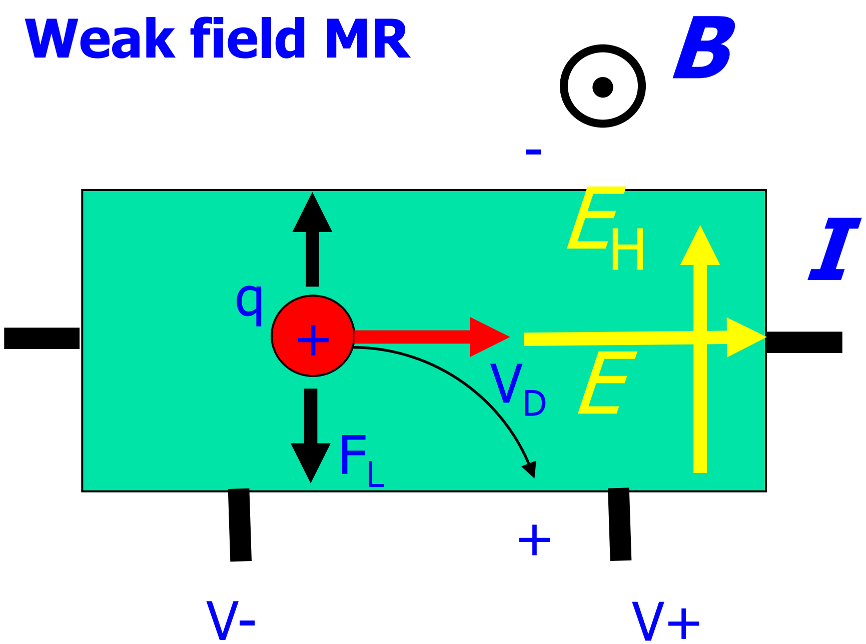


Hall effect: Lorenz force
Flowing charges in B

NE Steady state: no charge flow!
E_s compensates grad T force
N=0?
We met this situation before.
Where?

Magnetoresistance,
cyclotron orbit curvature is
compensated by Hall voltage
to first degree effect is zero

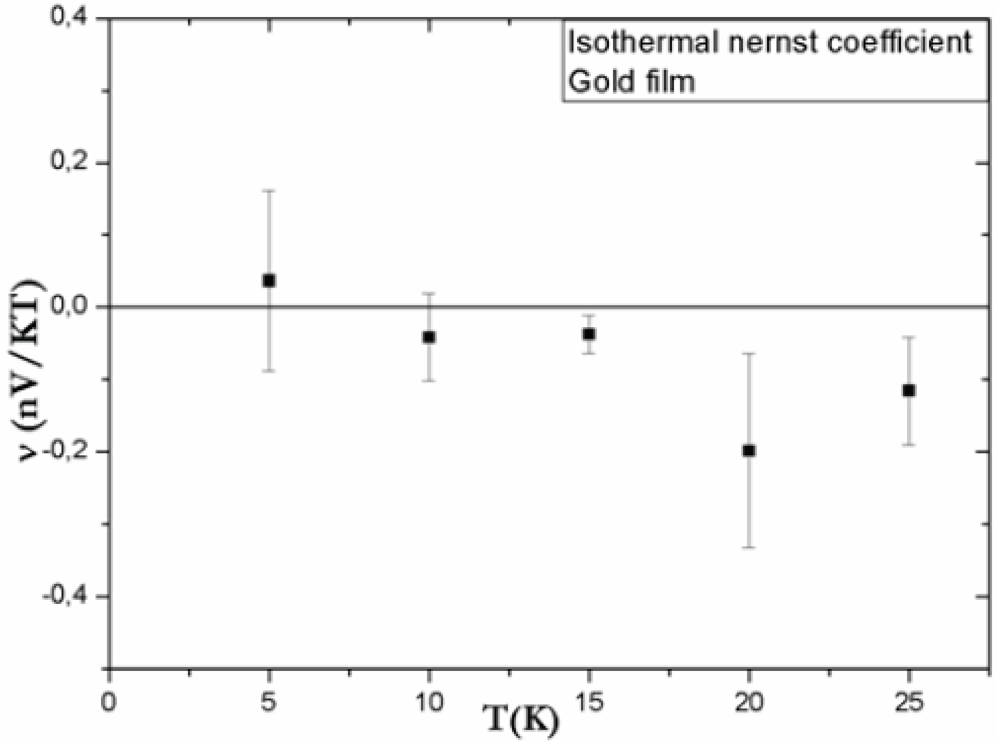
Weak field MR



Nernst effect is second order effect
DISTRIBUTION of velocities of carriers,
qE_s compensates average v_D,
but not hotter and colder than average

In SIMPLE metals for **"good scattering"**
N is negligibly small

Nernst effect in gold **~0.1 nV/KT**



PHYSICAL REVIEW B VOLUME 54, NUMBER 9 1 SEPTEMBER 1996-I

Nernst effect in anisotropic metals

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"Bad scattering"

Anisotropy notably increases Nernst effect

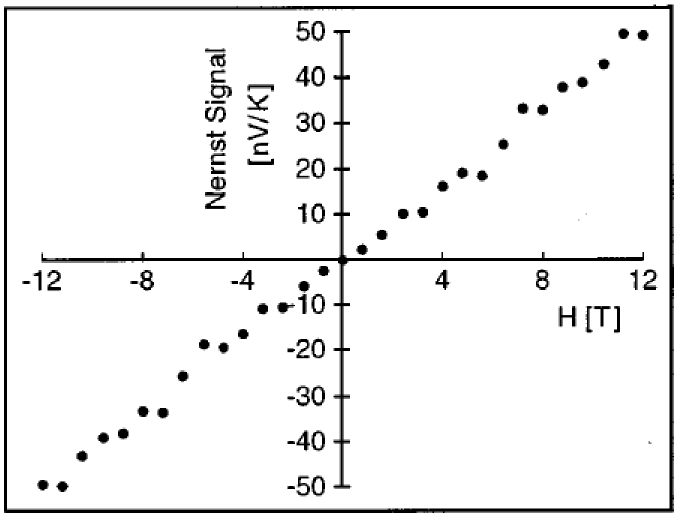

FIG. 2. Magnetic-field dependence of the raw Nernst signal at $T=250$ K showing the linear variation with the applied field strength.

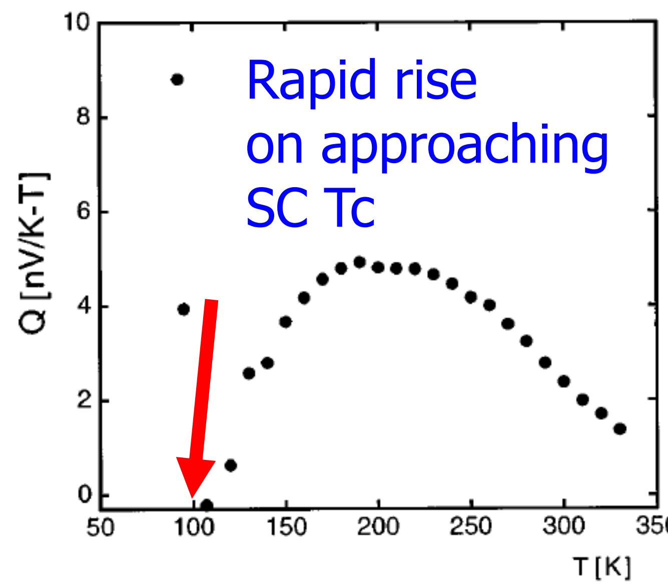

FIG. 3. Temperature dependence of the Nernst coefficient Q of the $YBa_2Cu_3O_{7-\delta}$ thin-film sample. Q goes to zero just above T_c, but increases rapidly at lower temperature, reflecting the large contribution from superconducting fluctuations.

YBCO

"Increased" N~5nV/KT!

Measurement of Nernst effect

Typical numbers

Metals

Good scattering ???

Anisotropic scattering 5 nV/kT

V<10 nV

Semiconductors

n~10^{16}-10^{24} m^{-3}

V~1-100 μV

Very demanding measurements from thermal stability and electrical noise point of view

Ideologically similar to Thermopower measurements

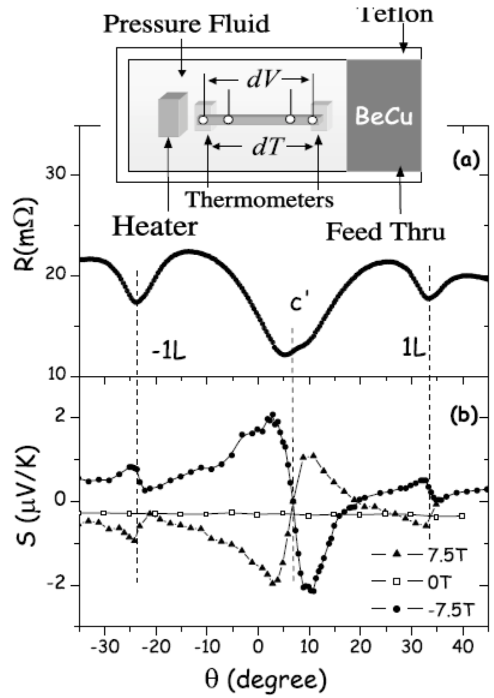

FIG. 1. The experiment setup. (Inset): Four Au wires were attached to the sample along the **a** axis. Two RuO thin film resistors thermometers were placed next to both ends of the sample to measure temperature gradient generated by a miniature heater. The angular dependence of the magnetoresistance (a) and the raw thermoelectric signal (b), $S = \Delta V/\Delta T$, for $(TMTSF)_2PF_6$ as a function of magnetic field direction for $\mathbf{b}^*\mathbf{c}^*$ plane rotation (2 K, 10 kbar). $\theta = 0$ is taken as $\mathbf{B} \parallel \mathbf{c}^*$. Note that S is essentially an odd function of applied field. The solid line is a guide to the eye.

Measurements

Nernst signal is defined as odd part of Sxy in field

$S_{xy}=S_{nonequipotential}+S_{MR}+S_{N}$

Measurements in positive and negative fields,
$Sxy(H)-Sxy(-H)=2S_{N}$

Fixed temperature +H to –H sweep
Time consuming

Strict requirements for T-drift, $Sxy(\delta T) << Sxy(H)$

REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 72, NUMBER 5 MAY 2001

Low-frequency method for magnetothermopower and Nernst effect measurements on single crystal samples at low temperatures and high magnetic fields

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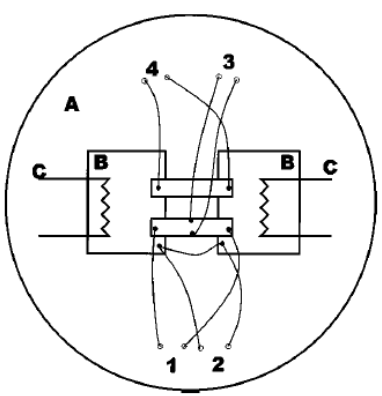

FIG. 1. Diagram of the measurement holder (the outer diameter of the cylindrical copper holder is 10 mm). A: Cu heat sink, B: quartz blocks, and C: heaters. 1: thermopower leads of sample, 2: Chromel–Au(Fe0.07%) thermocouples for ΔT leads, 3: Nernst voltage leads of sample, and 4: thermopower leads of reference YBCO sample.

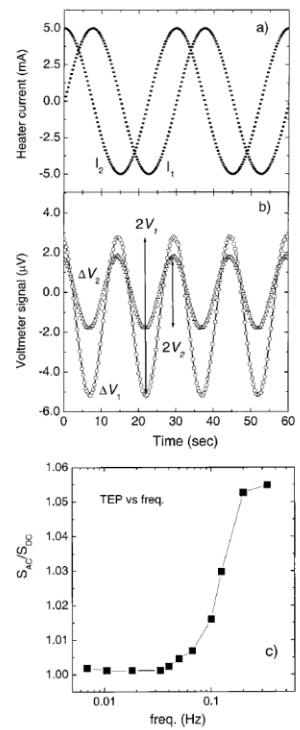

FIG. 2. (a) Heater currents and (b) $\Delta V_1(\Delta V_2)$ as a function of the time. T period of the heating cycle is 30 s and the corresponding periods of osc lation of temperature gradient and thermopower signal are 15 s. (c) S_{ac}/S vs frequency method used to determine the optimum frequency range whe $S_{ac}/S_{dc}\approx 1$ for the TEP measurements.

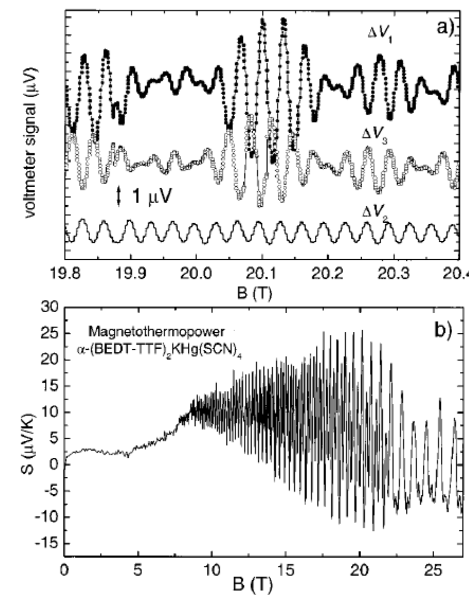

FIG. 4. Magnetothermopower. (a) ΔV_1, ΔV_2, and ΔV_3 curves under magnetic field for α-(BEDT–TTF)$_2$KHg(SCN)$_4$ at $T = 0.7$ K. (b) Derived magnetothermopower results. Note the narrow range of field in (a), which corresponds to only a few quantum oscillations in (b).

Why bother measuring Nernst effect?

- Additional insight into multiple carrier conductors
- Anomalous scattering, easy to detect sharp features in $\dfrac{\partial \sigma(\varepsilon)}{\partial \varepsilon}$
- Exotic scattering in magnetic systems

K. Behnia

•Thermoectricity as a probe of exotic states of correleted electrons is still largely underexplored.

Nernst effect in superconductors

PHYSICAL REVIEW VOLUME 181, NUMBER 2 10 MAY 1969

Nernst Effect and Flux Flow in Superconductors. I. Niobium*

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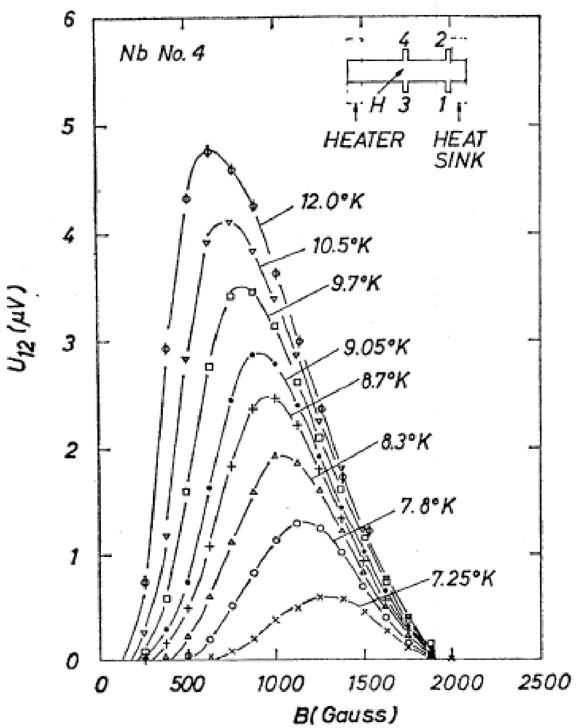

FIG. 2. Transverse voltage U_{12} versus magnetic field for different temperature gradients. The temperature at each curve is the value at the heater. (Specimen 4; temperature at heat sink $=4.2°K$.)

N is big in the mixed state of SC
Flux quanta respond to grad T
by thermal diffusion
generate Seebeck and Nernst voltages

Nernst effect in superconductors

Supercond. Sci. Technol. 8 (1995) 189–198. Printed in the UK

REVIEW ARTICLE

Superconductors in a temperature gradient

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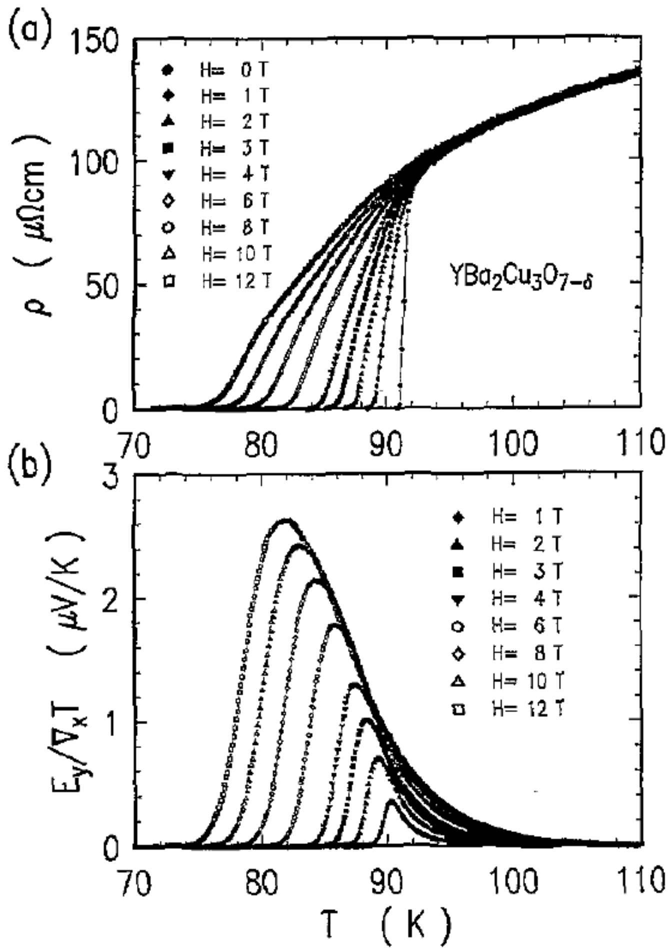

Figure 3. Resistivity ρ (a) and normalized Nernst electric field $E_y/\nabla_x T$ (b) versus temperature for an epitaxial *c*-axis-oriented $YBa_2Cu_3O_{7-\delta}$ film at different magnetic fields ($\boldsymbol{B} \| \boldsymbol{c}$).

Same big in high-Tc cuprates
But in a broader T-range

Vortex-like excitations and the onset of superconducting phase fluctuation in underdoped $La_{2-x}Sr_xCuO_4$

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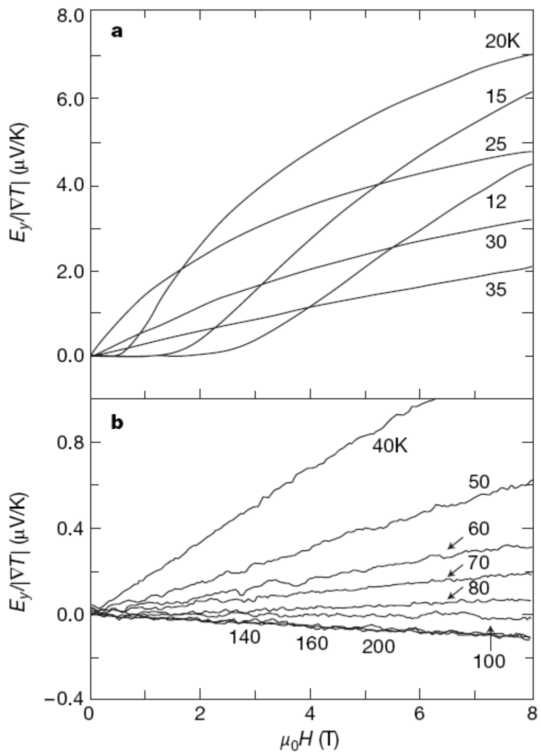


Figure 1 Nernst signals. **a**, The Nernst signal E_y (normalized to unit gradient) versus **H** ∥ **c** in $La_{2-x}Sr_xCuO_4$ (sample 3, $x = 0.10$) at temperatures 12–35 K. **b**, The Nernst signal from 40 to 200 K. Above 20 K, the applied gradient is 5 K cm^{-1}, while below 20 K, it is half as large. When vortex pinning is large ($T < 25$ K), E_y is zero over a range of $H < H_m$. Above 140 K, the curves tend asymptotically to a straight line of negative slope.

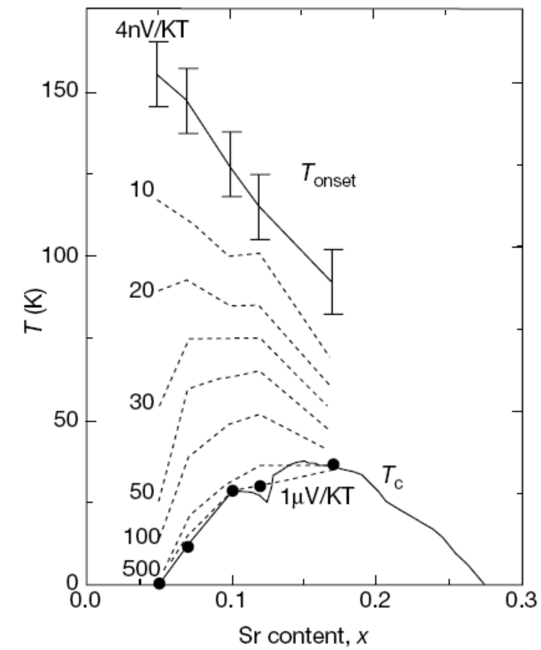
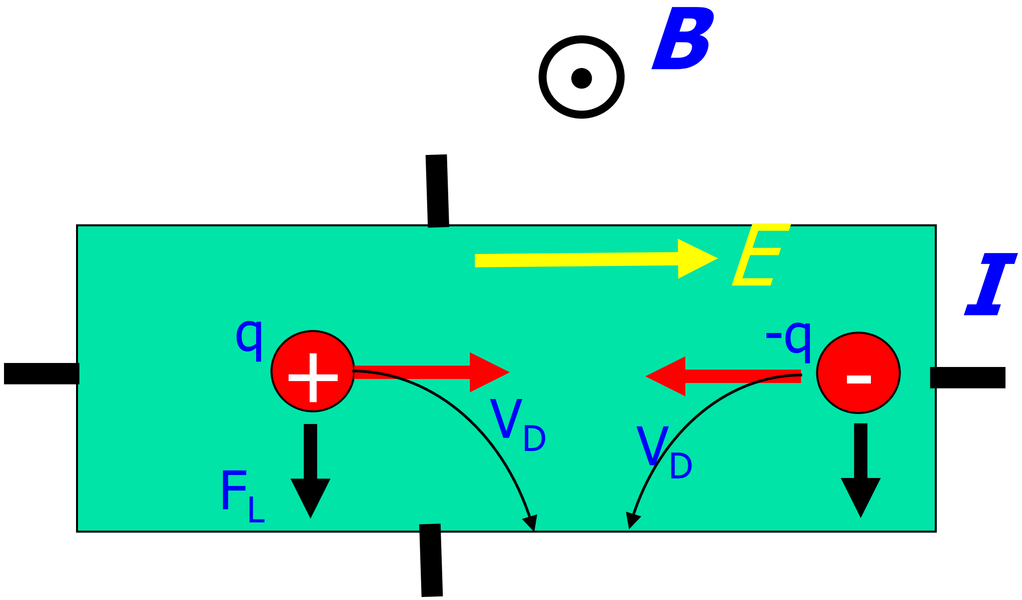


Figure 4 Contour plot of $(\nu - \nu_n)$ versus x in the phase diagram of LSCO. The contour plot displays how high in T the vortex-like excitations extend for each value of x. The upper solid line T_{onset} is the contour set by our resolution. The pseudogap T^* estimated from heat capacity[15] is about a factor of two larger than T_{onset}. Values of T_c in our samples (circles) match the T_c line (lower solid line) from Takagi *et al.*[14] We note that the T_c line is roughly similar to the contour line $\nu = 1$ μV/KT.

Claims:
Nernst effect is too big for a metal
Superconducting vortices above Tc
Preformed pairs scenario

Can Nernst effect be big otherwise?

To have big MR you need V_H=0



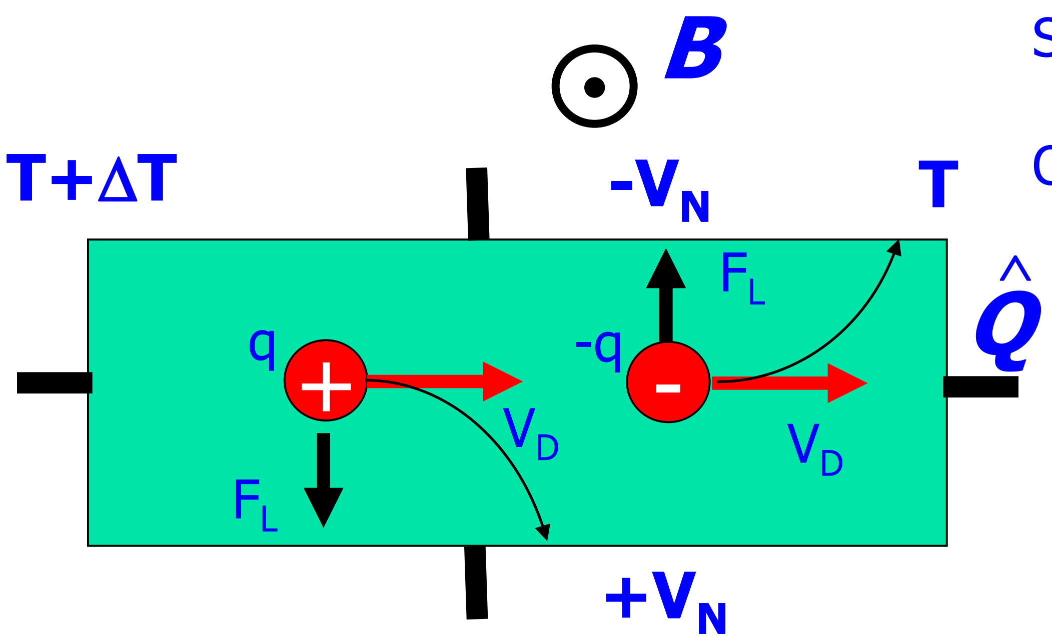
Q. What should we have =0 to get big Nernst effect?

A. S =0
Compensation of different carrier types

No compensation for cyclotron orbit curvature

When S=0 there is no restoring force and there is always a current of two carrier types in the same direction

Ambipolar Nernst effect



Contrary to Hall effect
Contributions of +q and –q
Sum up in ambipolar Nernst effect

Q. What is the difference?

One carrier type: Nernst is second order effect
Two carrier types: Nernst effect is FIRST order effect

Nernst effect Ge: big

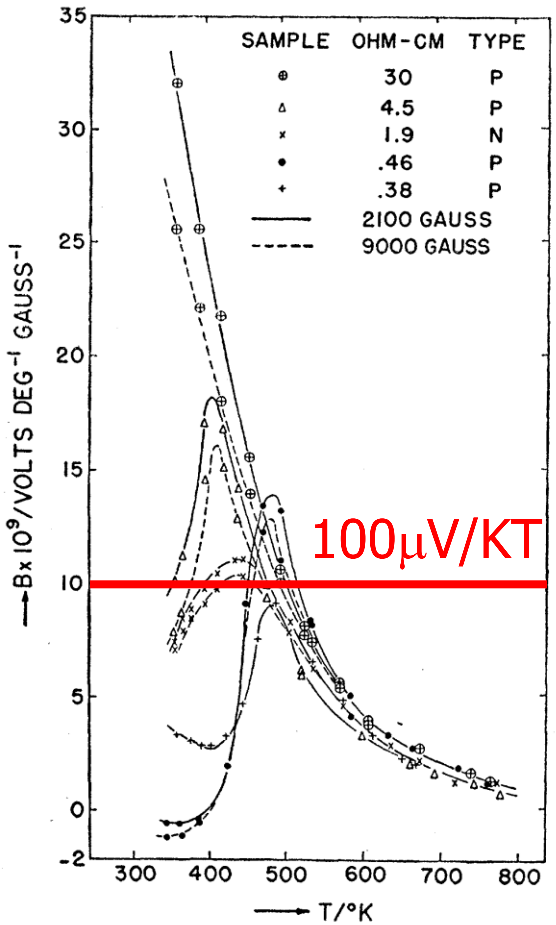


FIG. 2. Experimental Nernst coefficient, B, in n- and p-type germanium of different resistivities, as a function of temperature between 300 and 750°K, measured at 2100 and 9000 gauss.

Semiconductors
First observation
Krylova TV, Mochan IV, J. Tech. Phys. (USSR) 25, 2119 (1955)

N is very big in narrow gap semiconductors

Number of unknowns=number of equations
To solve transport completely
you want to measure
Single carrier type: resistivity +Hall
Second carrier type: +Seebeck +Nernst

VOLUME 91, NUMBER 6 PHYSICAL REVIEW LETTERS week ending 8 AUGUST 2003

Not negligible even in metallic systems!

Ambipolar Nernst Effect in $NbSe_2$

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(Received 13 February 2003; published 5 August 2003)

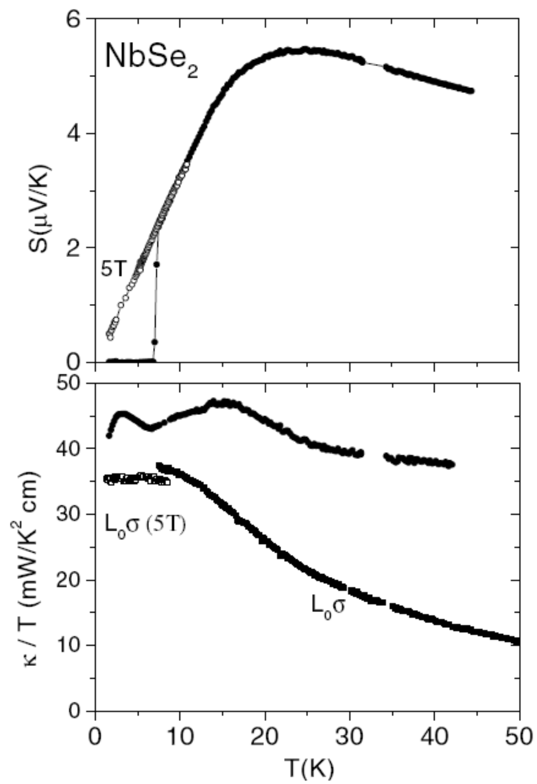

FIG. 2. Upper panel: thermopower (S) of $NbSe_2$ at $H = 0$ (solid circles) and $H = 5$ T (open circles). Lower panel: thermal conductivity divides by temperature (solid circles) as a function of temperature. Also shown is the charge conductivity (σ) at $H = 0$ (solid squares) and at $H = 5$ T (open squares) multiplied by the constant L_0 (see text).

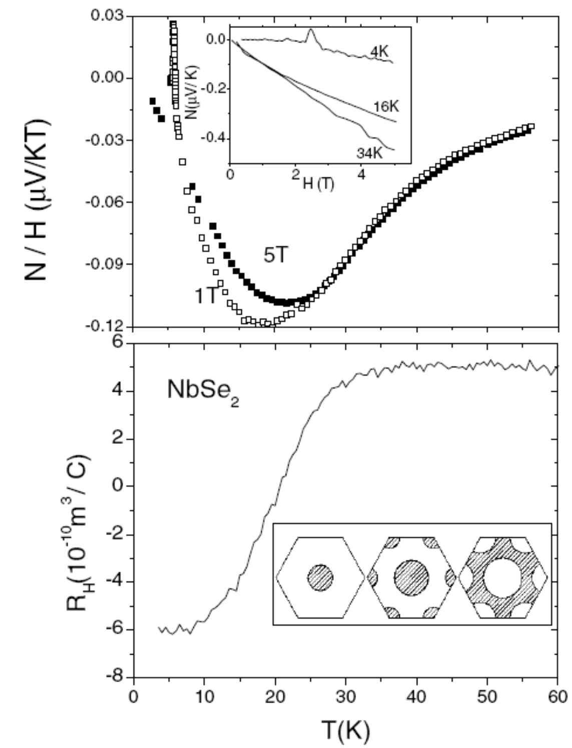

FIG. 3. Upper panel: the Nernst coefficient as a function of temperature at $H = 0$ and $H = 5$ T. The inset compares the field dependence of the Nernst signal at three different temperatures. Lower panel: the temperature dependence of the Hall coefficient measured at $H = 5$ T. Inset: a schematic plot of the three-band Fermi surface in $NBSe_2$ as observed by angular-resolved photoemission spectroscopy (ARPES) [11].

Nernst effect is big when weak field MR is big: Compensation+ high mobility

Bi metal 200% MR in 2T at room temperature

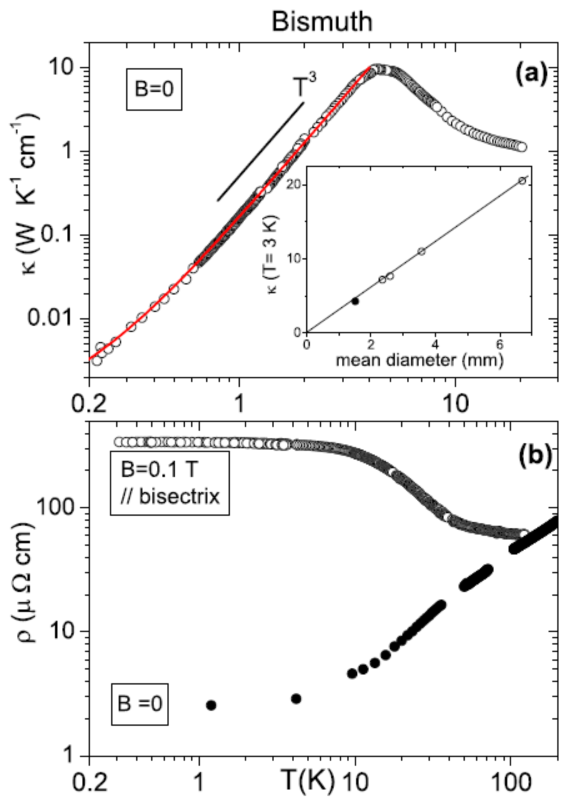

FIG. 1 (color online). (a) Thermal conductivity, κ of the Bi single crystal. Solid line represents a $aT + bT^3$ fit (see text). Inset compares the magnitude of $\kappa(3K)$ of the sample of this study (solid circle) with those reported in Ref. [15] (open circles) as a function of mean diameter. (b) Resistivity of the same sample at zero field and in presence of a field of 0.1 T.

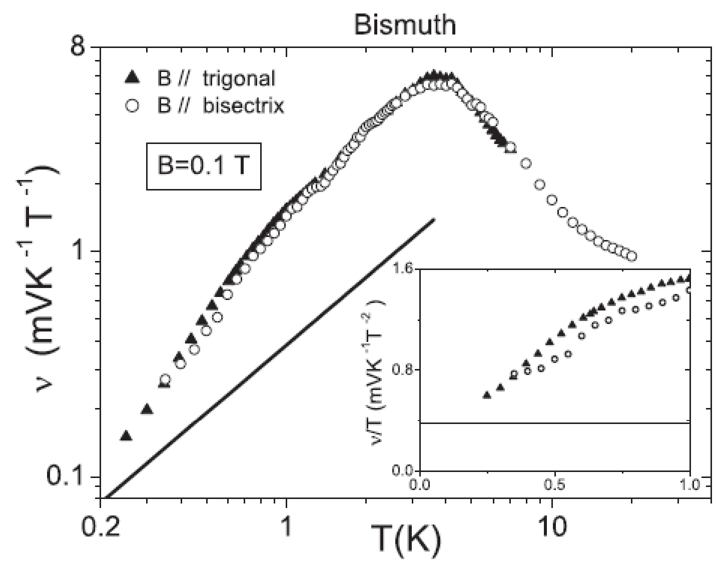

FIG. 2. The temperature dependence of the absolute value of the Nernst coefficient of the bismuth single crystal for two different orientations of the magnetic field. The solid line represents a linear function αT with $\alpha = 283 \frac{\omega_c \tau}{\epsilon_F B} = 0.38$ mV K^{-2} T^{-1} (see text and Table I). Both this function and the low-temperature data are displayed in the inset as a ν/T vs T plot.

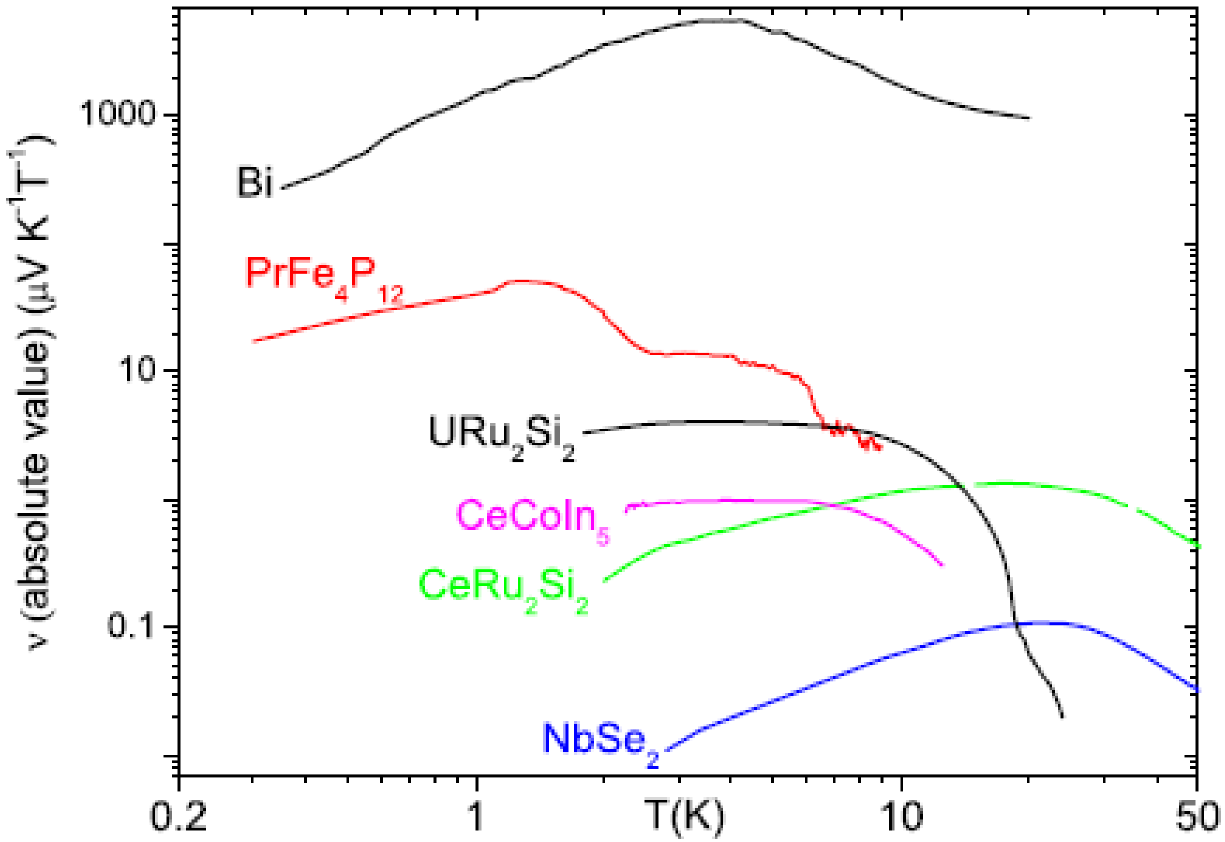

FIG. 3 (color online). The magnitude of the Nernst coefficient in bismuth compared to what is found in some other metals [4,5,7,8,12].

K. Behnia group

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Giant Nernst Effect and Lock-In Currents at Magic Angles in $(TMTSF)_2PF_6$

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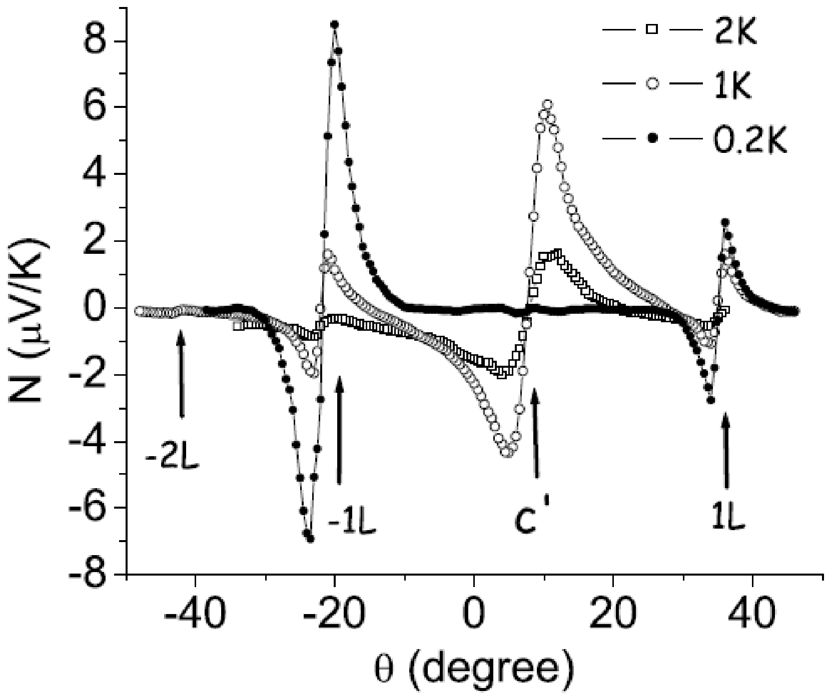

FIG. 2. Angular dependence of the Nernst signal at 2, 1, and 0.2 K, $B = 7.5$ T showing the rapid growth with lower temperature. We have used $N = \frac{S(B)-S(-B)}{2}$ as our definition for the Nernst signal.

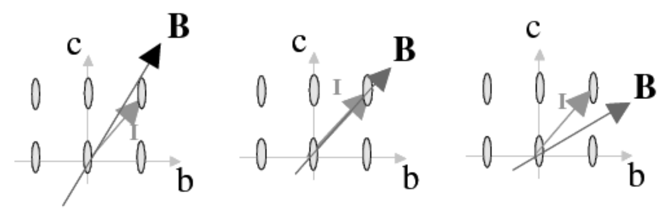

FIG. 4. Looking down the TMTSF chains. For the field near the **b** + **c** direction the current flows only between the chains separated by **b** + **c**. The Lorentz force then produces a force along **a** in the first figure, along −**a** in the last figure, and no force in the middle figure when the field and the current are parallel. Note that here we use an orthorhombic approximation.

Reading:
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R. P. Huebener, Supercond. Sci. Technology 8, 189 (1995).

Nernst effect in exotic materials
K. Behnia, virtual lecture at *hvar05.ifs.hr/workshop/work_**lectures**.html*

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